Received: 6 June 2018 | Revised: 23 August 2018 | Accepted: 28 September 2018
DOI: 10.1002/jcu.22657

WILEY

RESEARCH ARTICLE

Accuracy and reliability of bedside thoracic ultrasound in detecting pulmonary pathology in a heterogeneous pediatric intensive care unit population

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Abstract

Purpose: This study was designed to access sensitivity and specificity of detection of lung abnormalities by the ultrasound (US) done by PICU providers of varying levels of experience compared to CXR and to assess the inter-rater reliability in the interpretation of the USG findings.

Methods: Up to three US examinations were performed on patients meeting eligibility criteria. US examinations were reported by the operator and remotely by an expert reader. Both operator and readers interpretation were correlated with CXR read by an independent pulmonologist.

Results: One hundred and thirty-five US examinations were performed on 91 patients over 9 months. Overall agreement between the operator and reader of the US was 0.53 (0.38-0.68). The agreement was highest with an expert-expert pair (0.75) and lowest with a novice-expert pair (0.27). Sensitivity and specificity of thoracic US to detect pulmonary abnormalities showed a high sensitivity by the operator (82.5%) compared to the reader (63.4%). Specificity was 25% and 42.8%, respectively. US was overall highly sensitive to detect pneumonia (96.4%) with a 100% PPV, but only modest for bronchiolitis.

Conclusions: Lungs US is a rapid and sensitive bedside tool to assess lung consolidation in children in ICU. It, however, has low negative predictive values, and negative US examinations cannot rule out lung pathology.

KEYWORDS

bedside US, bronchiolitis, pediatrics, pneumonia, thoracic US

1 | INTRODUCTION

Bedside, critical care ultrasound (US), is a novel tool that can rapidly and accurately provide a wealth of information for clinicians. The practice of bedside sonography by clinicians was popularized and standardized by emergency medicine trained physicians[1] and gradually spread to other clinical specialties such as critical care, anesthesia, and surgery. Many researchers have shown good predictive values with the use of sonography for assessing fluid responsiveness, measuring cardiac output, diagnosing pneumonia, and detecting abdominal trauma using focused assessment with sonography for trauma (FAST).[2] For a very long time, thoracic sonography was considered to be a substandard modality for imaging lung parenchyma due to poor penetration of sound waves through the air-filled lung. However, work by Lichtenstein and others have shown the utility of specific artifacts observed during thoracic sonography in predicting various lung pathologies.[3,4] There is now a growing body of evidence from adult medical literature suggesting that bedside sonography by non-radiologists can detect various lung pathologies with high sensitivity and specificity.[5,6]

A review of the pediatric literature shows that some studies have been performed in an emergency room (ER) setting[7–10] and within radiology suites,[11,12] and have shown good sensitivity of thoracic sonography in detecting pneumonia,[13] and good correlation between sonographic findings of pneumonia and computerized tomography (CT) scans.[11,14] However, the patient population in pediatric intensive care unit (PICU) setting is quite different from patients seen in outpatient radiology settings. While a pediatric ER will also see a wide variety of disease states and levels of acuity, due to self selection of critically ill patients, prevalence of pulmonary disease states would be different in PICU patients than ER. PICU patients are also predominantly supine and nonambulatory, which poses additional challenges to performing and interpreting thoracic sonographic imaging. Furthermore, many studies exploring thoracic sonography in pediatric settings have focused solely on the detection of pneumonia, rather than the full spectrum of pulmonary pathologies that can be detected by bedside US examinations in the pediatric ICU. To our knowledge, there have been no studies conducted in the PICU setting exploring the utility of thoracic sonogram performed at the bedside by PICU providers. A survey in 2011 explored the use of bedside sonography in the PICU setting but did not include any questions regarding the use of thoracic sonography to detect pneumonia or pulmonary edema, suggesting a lack of awareness even among academic pediatric intensivists regarding the utility of bedside sonography in detecting pulmonary pathology in the pediatric ICU.[15] We designed this study with the objective of determining the sensitivity and specificity of bedside thoracic sonography for detecting lung abnormalities when performed by PICU providers and compared to chest x-rays (CXR). Our secondary objective included the assessment of interrater reliability in the interpretation of thoracic sonograms performed by PICU providers with varying levels of expertise.

2 | MATERIALS AND METHODS

2.1 | Study design and setting

We conducted a prospective observational study from September 2016 through June 2017 in the PICU and pediatric intermediate care (PIC) unit at the Children's Hospital of Illinois at Peoria (CHOI) at OSF St Francis Medical Center (OSF). This is a pediatric academic center affiliated with the University of Illinois College of Medicine at Peoria (UICOMP), and serves a sizeable pediatric population as the only free-standing children's hospital in Peoria. PIC at Children's Hospital of Illinois is a relatively high acuity unit, which frequently admits patients with respiratory de-compensation requiring noninvasive respiratory support. The study was approved by UICOMP/OSF Institutional Review Board (IRB).

2.2 | Inclusion and exclusion criteria

All children between ages of 0 and 17 years that were admitted to the PICU and pediatric intermediate care unit were eligible for enrollment if they had signs and symptoms of respiratory distress, or if they required respiratory support in the form of supplemental oxygen, noninvasive positive pressure ventilation, or intubation and mechanical ventilation.

We excluded children who had undergone cardiac surgery or other intrathoracic procedures during the current hospital admission, as well as patients with chest tubes in place, or patients on extracorporeal membrane oxygenation (ECMO) support. Patients who had behavioral issues or were deemed uncooperative for other reasons were also excluded from our study. Lastly, patients who did not have a chest x-ray performed during the admission were excluded.

2.3 | Patient enrollment

Every 24 h, we reviewed patient charts for all admissions to the pediatric intermediate and intensive care units to evaluate for eligibility in the study. If patients satisfied the inclusion/exclusion criteria, our study coordinators approached the child's parents to obtain informed consent for participation in the study. For children who were 8 years or older, we also obtained assent from the patient.

After enrollment, bedside thoracic sonogram was performed and interpreted by one of the following three investigators: ST, HG, or EM. We ensured that the investigator performing the sonogram was not directly involved in the subject's clinical care. If the patient remained admitted to the intermediate or intensive care unit beyond the day of recruitment, we repeated US imaging every other day, for a maximum of three sonograms per patient. Each chest sonogram was counted and analyzed as a separate subject.

2.4 | Sonographic approach

All investigators performing chest sonograms (ST, HG, and EM) have received some form of prior training in operating US machines, and before initiating patient enrollment, they collectively performed thoracic sonograms on multiple random patients in the PICU. This continued until they established uniformity in their practice, and demonstrated competency in lung sonography as described by American College of Chest Physicians consensus statement on competence in critical care sonography.[16] Each of these "operators" are clinicians with varying levels of experience in delivering pediatric critical care and performing bedside sonography: ST was considered the "expert" with more than 5 years of post-fellowship pediatric critical care and sonography experience, HG was considered "intermediate" with 1 year of post-fellowship experience, and EM was considered the "novice" due to the lack of fellowship training or prior sonographic experience.

The operators performed all sonographic imaging with the Sonosite X-Porte (FUJIFILM SonoSite Inc), using previously published technique[4] that was adapted to our study population (Figure 1). This involved evaluation of four zones in each hemithorax: anterior-superior, anterior-inferior, lateral-superior, and lateral-inferior. Nipple line delineated the superior and inferior zones, and the anterior and posterior axillary lines delineated the anterior and lateral zones. As majority of our patients were supine, we did not access posterior lung zones in our protocol. While this potentially decreased identification of posterior lung fields, we believe that the tradeoff was essential for comfort and safety of critically ill children.

Imaging was performed in the supine or reclining position using a 1-5 MHz phased array transducer probe, and each investigator adjusted the depth and gain as needed depending on patient size. We first evaluated for bilateral lung sliding with two-dimensional and M-mode imaging to rule out pneumothorax and then proceeded to thoroughly scan all intercostal spaces in the long axis view, searching for pleural lines, A-lines, B-lines, or C-pattern. Pleural line was defined as hyperechoic line

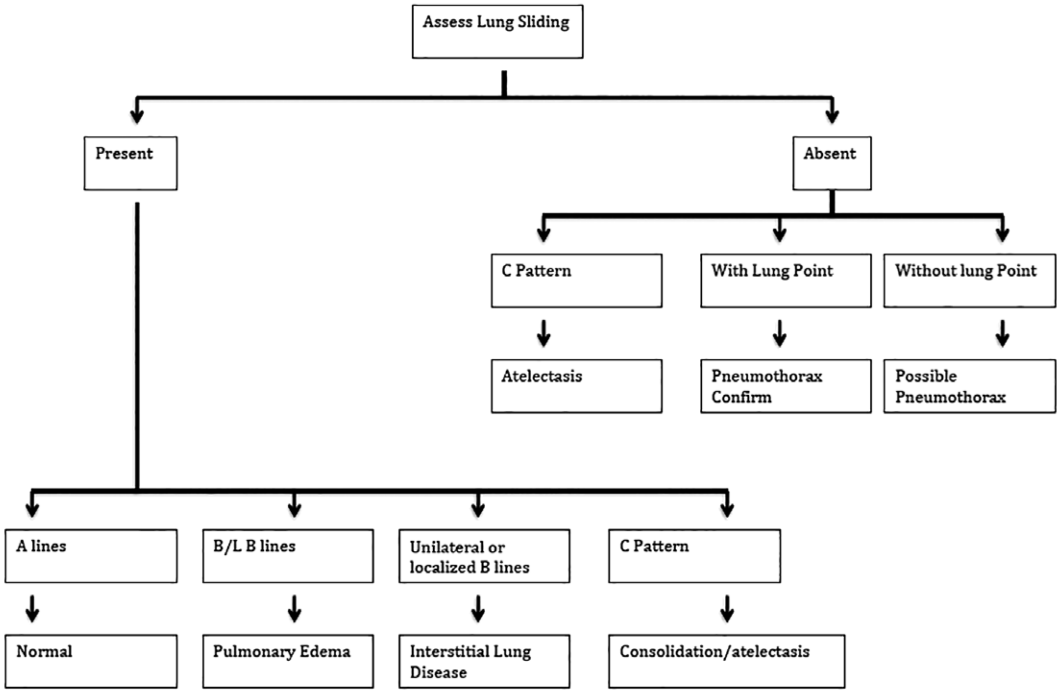

FIGURE 1 Ultrasound image acquisition protocol

visible below the rib line, A-lines as horizontal lines, arising from and parallel to the pleural line. B-lines as vertical lines arising from and perpendicular to the pleural line, and C-pattern was defined as presence of tissue pattern with air Broncho grams in one or more lung regions.[5] While imaging the lateral-inferior lung zones, we also visualized the lung base and diaphragm and evaluated for the presence of pleural effusions in the posterior costo-phrenic angle. A representative 5-s video clip was recorded for each lung zone, and still, images were captured for the M-mode representation of lung sliding.

2.5 | Data collection and analysis

The investigator performing the US (ST, HG, or EM) was made aware of the subject's clinical presentation but blinded to the CXR findings. After correlating US findings with the clinical history, the investigator reported his sonographic findings and diagnostic impression, which were then collected and managed using Research Electronic Data Capture (REDCap) hosted at University of Illinois at Chicago. To perform quantitative analyses comparing US and CXR findings, the CXR interpretation had to be standardized in a format that corresponded with sonogram reading (ie, abnormal findings reported by the four lung zones described above). Therefore, co-investigator MM who is a senior pediatric pulmonologist, served as the “CXR reader” and reviewed and interpreted all CXR images for the study subjects, and recorded his findings and diagnostic impression into REDCap database. Similar to the investigators performing chest sonography, co-investigator MM was aware of the patient's clinical diagnosis but blinded to the sonograms and sonographer's diagnostic impression. A pulmonologist (as opposed to a radiologist) was chosen to maintain ‘clinical’ interpretation of the CXR. Another intensivists would have been ideal for our study, however it would have been difficult to maintain true “blinding” of the CXR findings.

To test for inter-observer variability, all sonographic images and video clips obtained by the operators were reviewed and interpreted by coinvestigator JP, who is also a clinician with extensive experience in the use of bedside sonography in critically ill children, and was considered an “expert” and “sonogram reader” for the purpose of this study. Like other investigators, JP only had access to demographic information and clinical diagnosis and was blinded to CXR or US interpretation by other coinvestigators.

To standardize reporting of diagnoses, the operators, sonogram reader, and CXR reader were asked to report diagnostic impressions as one (or more) of the following six summary opinions: pneumothorax, pneumonia, atelectasis, pulmonary edema, pleural effusion, and interstitial lung disease. Additionally, we also asked the primary PICU provider caring for the patient to provide their clinical summary opinion, thereby allowing us to study the agreement between sonographic interpretation by the operators and the primary clinical team's working diagnosis.

Analyses were performed on SAS and JMP statistical software (SAS Institute, NC). We determined the interrater agreement between operators and the readers using Cohen Kappa statistic (κ) and its 95% confidence interval (CI), with the interpretation as follows: κ <0, poor agreement; κ 0.01-0.20, weak agreement; κ0.21-0.40, fair agreement; κ 0.41-0.60, moderate agreement; κ0.61-0.80, good agreement, and κ 0.81-1, excellent agreement. Due to the varying skill and experience level of each operator (expert, intermediate, and novice), we further analyzed the interrater agreement between each operator and the sonogram reader, thereby generating three pairs of analyses: expert-expert, intermediate-expert, and novice-expert. Similarly, Kappa statistic was also calculated to determine the strength of agreement between the operators/readers and the clinical team.

3 | RESULTS

Over the course of 10-month study duration, we enrolled a total of 91 children in the study, and attempted 135 thoracic sonograms, with 129 completed successfully (95% success rate). Six US examinations could not be completed due to patient agitation. Of the 91 patients enrolled, 31 children had two chest sonograms performed, and 13 children had three US examinations performed as per protocol, with the remaining patients undergoing only one thoracic sonogram. The median age of our study population was 44 months, with a majority of children between 1 month and 5 years of age (n = 73). We recorded the time taken to complete each sonographic study by documenting the time that the US machine was "wheeled in" and "wheeled out" of the patient's room. This was similar across all age groups (Median time = 15 min, IQR 10-20 min), except for neonates, for whom it took twice as long (Median time = 30 min), although the low number of neonates (n = 3) makes this finding unreliable. Almost 50% of the sonograms were performed and reviewed by the expert-expert pair, with the remaining between intermediate-expert and novice-expert pair. Diagnoses of the subjects mirrored a typical PICU population requiring respiratory support, with top three diagnoses being bronchiolitis, pneumonia and status asthmaticus. High flow nasal cannula (HFNC) is the most common mode of noninvasive respiratory support in our ICU, which is reflected in our results: 48% of our subjects were on HFNC for respiratory support, and 35% of our patients had an artificial airway either in the form of endotracheal tube or tracheostomy. A substantial proportion of CXRs were reported abnormal by the pulmonologist interpreting x-ray images (87.7%). Similarly, 80.6% of sonograms were reported as abnormal by the operators. However, the reader reported only 62.2% of the US examinations as abnormal. (Table 1).

TABLE 1 Demographics of the study population

	Category		Value
1	Total patients		91
2	Total ultrasounds		135
	Success rate		129/135 (95%)
3	Medical vs surgical	Medical	128 (95%)
		Surgical	7 (5%)
4	Age distribution	Median	44 month (IQR 5.2-109.1)
		< 1 mo	3 (2.2%)
		1 mo to 1 y	44 (32%)
		1 y to 5 y	29 (21%)
		>5 y	59 (43%)
5	Percentage males		N = 81 (60%)
6	Time to complete ultrasound	Median	15 min (IQR 10-20)
		< 1 mo	30 min (IQR 10-30)
		1 mo to 1 y	15 min (IQR 10-19.5)
		1 y to 5 y	17 min (IQR 10-20)
		>5 y	15 min (IQR 10-20)
7	Investigator numbers	ST	N = 70 (52.2%)
		HG	N = 34 (25.3%)
		EM	N = 30 (22.3%)
8	Diagnosis	Bronchiolitis	N = 60 (44.4%)
		Pneumonia	N = 30 (22.3%)
		Asthma	N = 16 (11%)
9	Respiratory support	High flow	N = 65 (48%)
		Mechanical ventilation	N = 48 (35%)
		Nasal cannula	N = 14 (10%)
		BiPAP/CPAP	N = 6 (4%)
		Face mask/ NRB	N = 1 (0.7%)
10	Prevalence of abnormal CXR		N = 115 (87.7%)
11	Prevalence of abnormal ultrasound by operator		N = 104 (80.6%)
12	Prevalence of abnormal ultrasound by reader		N = 76 (62.2%)

Using CXRs as a gold standard to detect pulmonary abnormalities, we found thoracic sonograms to have a high sensitivity of detection by the operators (82.5%) and somewhat lower by the sonogram reader (63.4%). Specificity was low overall (42.8% for the sonogram reader and 25% for the operators). Operators and sonogram reader also had a very high positive predictive value (probability of the CXR being abnormal when the sonogram was abnormal) of 82% and 89%, respectively, but a very low negative predictive value (probability of CXR being normal when US was normal) of 17.4% and 13.6%. Among the three operators, specificity was highest for the expert operator (50%), whereas sensitivity was highest for the novice operator (95.2%). We also found that thoracic sonography had the lowest sensitivity when imaging infants (77.1%), and highest for children greater than 5 years of age (85.7%). When stratified by different pathologies, thoracic sonograms had high sensitivity for detecting pneumonia (96.4%) with a 100% positive predictive value, but only modest sensitivity for detecting bronchiolitis (79.1%). Chest sonograms were relatively more specific for detecting lung abnormalities among patients on mechanical ventilation (50%) when compared to patients on HFNC support (14.2%) (Table 2).

When assessing for binary outcome of normal versus abnormal, we found moderate overall agreement between the operator and reader of sonograms (κ 0.53, CI 0.38-0.68). The agreement was highest between the expert-expert pair (κ 0.75, CI 0.58-0.92) and lowest between the novice-expert pair (κ 0.27, CI –0.04-0.58). We also calculated Kappa statistic separately for the first 45 subjects and the last 45 subjects and did not observe any difference, suggesting that experiential learning by the operators over the course of the study did not influence interrater reliability. Highest agreement was noted for the age group of 1-5 years (κ 0.63, CI 0.32-0.94), and lowest agreement noted for infants (κ 0.43, CI 0.03-0.66).

Both the operator and sonogram reader had 100% agreement for the presence or absence of B-lines or C-pattern. However, the agreement was moderate for regional localization (anterior, posterior, or both). When evaluating for exact segmental localization (right and left anterior-superior, anterior-inferior, lateral-superior, and lateral-inferior), we found good agreement between operator and sonogram reader for C-pattern

TABLE 2 Sensitivity analysis (sensitivity of ultrasound by the operator to detect pulmonary abnormality as compared to CXR read by a pediatric pulmonologist)

		Category	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
1	Overall (operator)		82.5	25	82.2	17.39
2	Overall (reader)		63.4	42.8	89.1	13.6
3	Investigator	ST (expert)	77.0	50	94	17.6
		HG (intermediate)	85.1	25	88.4	20.0
		EM (novice)	95.2	NA[a]	77.7	NA[a]
4	Age	< 1 y (*n* = 41)	77.1	33.3	87.3	20
		1 y to 5 y (*n* = 28)	84	NA[a]	87.5	NA[a]
		>5 y (*n* = 56)	85.7	28.5	89.3	22.2
5	Diagnosis	Bronchiolitis (*n* = 52)	79.1	NA[a]	90.4	NA[a]
		Pneumonia (*n* = 28)	96.4	NA[a]	100	NA[a]
6	Respiratory support	Mechanical ventilation	85.3	50	94.5	25
		HFNC (*n* = 59)	82.6	14.2	87.7	10.0

Abbreviations: PPV, positive predictive value; NPV, negative predictive value; HFNC, high flow nasal canula.
[a] Specificity could not be calculated due to lack of true negative.

segment localization, (κ 0.62, CI 0.43-0.81), but only fair agreement for B-lines segment localization (κ 0.30, CI 0.18-0.41). The agreement was lowest when the primary admitting diagnosis was asthma (κ 0.37, CI −0.03-0.78), while it was highest for bronchiolitis patients (κ 0.54, CI 0.33-0.76). Kappa statistic for the agreement of summary opinion between operator and sonogram reader was modest (κ 0.42, CI 0.32-0.53). There was a modest agreement between the operator's summary opinion and the clinical summary opinion (κ 0.49, CI 0.38-0.60), while the agreement between sonogram reader's summary opinion and clinical summary opinion was only fair (κ 0.27, CI 0.17-0.38). There was almost no agreement between the CXR reader's summary opinion and clinical summary opinion (Table 3).

4 | DISCUSSION

In this study, we have described the utility and feasibility of bedside thoracic US performed by clinicians in a mixed medical-surgical PICU. Our study population and level of respiratory support reflect typical medical-surgical PICU patients in North America. We also care for

TABLE 3 Agreement statistics

	Variable		Kappa[a]	Confidence interval
1	Overall		0.53	0.38-0.68
2	Investigator	Expert-expert	0.75	0.58-0.92
		Intermediate-expert	0.28	0.03-0.53
		Novice-expert	0.27	−0.04-0.58
3	Age	< 1 y	0.43	0.30-0.66
		1 y–5 y	0.63	0.32-0.94
		>5 y	0.51	0.24-0.77
4	Early vs late	First 45 studies	0.54	0.31-0.78
		Last 45 studies	0.55	0.29-0.81
5	B pattern only	N = 63 by both	1	
6	C pattern only	N = 33 by both	1	
7	B pattern regional	Ant/post or both	0.51	0.33-0.70
8	C pattern regional	Ant/post or both	0.49	0.23-0.74
9	Exact B pattern localization	Combinations of R1,R2,R3,R4,L4,L5,L6,L7,L8	0.30	0.18-0.41
10	Exact C pattern localization	Combinations of R1,R2,R3,R4,L4,L5,L6,L7,L8	0.62	0.43-0.81
11	Diagnosis	Bronchiolitis	0.54	0.33-0.76
		Pneumonia	0.47	−0.12-1.0
		Asthma	0.37	−0.03-0.78
12	Summary opinion by operator and clinical diagnosis		0.49	0.38–0.60
13	Summary opinion by reader and clinical diagnosis		0.27	0.17-0.38
14	Summary opinion operator and summary opinion reader		0.42	0.32-0.53
15	CXR interpretation and clinical diagnosis		0.04	0.00-0.83

[a] Kappa values for agreement between operator and reader for detection of various lung abnormalities on thoracic ultrasound.

post-cardiac surgery patients in our PICU, but they were excluded from this study as it was impossible to blind the presence of chest tubes and drains that could potentially bias the investigators towards positive findings. Prevalence of abnormal CXR findings in our study was quite high at 87.7%. It must be noted that we only recruited children requiring some form of respiratory support, which would suggest a high likelihood of pulmonary pathology, and explain the high incidence of abnormal CXR findings in our study sample. CXR interpretation, however, carries a degree of subjectivity and interrater agreement even among radiologists in interpreting CXR is not very high.[17,18] Similarly, while we report the prevalence of abnormal US (80.6% or 62.2%, depending on operator identified abnormalities or reader identified), this is not true prevalence as study population did not include all patients who were admitted to the PICU or a random sample of the patients. Median time to complete bedside US in our study (15 min) was similar to the prior reported range of 7-20 min.[7]

Our primary study objective was to evaluate the sensitivity and specificity of bedside thoracic sonograms in detecting lung pathology when compared to CXRs as a gold standard. Sensitivity and specificity of pediatric thoracic US in detecting pneumonia when CXR is considered as the gold standard has been reported to be 96% (C.I 94-98%) and 84% (C.I 80-88%) based on a recent meta-analysis.[19] Our data show comparable sensitivity but much lower specificity. In particular, our specificity and negative predictive value were low while the positive predictive value is acceptable. Thus if US is positive, chances of an abnormal CXR are high however a normal US cannot reliably predict a normal CXR. These findings are similar to the conclusions by Zhan et al[7] and Shah et al.[8] Most existing reports have only studied the use of thoracic sonography for detecting pneumonia, for which our sensitivity was comparable (96.4%) with a 100% positive predictive value. As opposed to bronchiolitis, detection of pneumonia by consolidation has been shown to be more accurate. Lung consolidation has fluid-filled areas, thus favorable for sound waves to propagate. Lung consolidation has been shown to touch the wall in 98% of cases, which is ideal for detection by US.[20] We additionally evaluated for a wide range of lung abnormalities including the presence of interstitial fluid (suggested by the presence of B lines), which is difficult to quantify on CXR and involves a high degree of subjectivity on US imaging,[21] and likely contributed to lower overall sensitivity and specificity in our sample. Agreement for diagnosing interstitial disease on US has been shown to be 0.32 by radiologist[11]and 0.08 by ED providers.[22] Prior studies on US findings in bronchiolitis showed that B-lines were not always present in patients with bronchiolitis and presence or absence of B-lines was not associated with disease severity.[22] Moreover, in some patients, LUS can identify lung abnormalities not seen by CXR.[23] In our study, CXR and USG were not done consecutively and an arbitrary time limit of 24 h was chosen for practical reasons. In rapidly evolving PICU patients, 24 h may be a significant time interval for lung pathology to shift especially the dynamic findings of interstitial fluid, thus accounting for the low agreement between CXR and US. Limit of 24 h has also been used by other studies.[7]

We found the sensitivity of bedside thoracic sonogram to be highest with novice operator but somewhat lower with an expert operator. This might be explained by the inexperienced operator having a higher tendency to call a finding abnormal, thus increasing sensitivity. Understandably, the most experienced operator had the highest specificity for identifying abnormalities. This is similar to the previous reports.[19] However, some prior studies have shown that learning chest sonography is relatively easy with a few hours of tutoring.[24,25] Our data does not support this argument as we did not find any increase in interrater agreement from the onset of the study to the tail end of the study. This may be attributed to our study protocol which did not allow investigators to discuss sonograms and their interpretations during the study period, whereas residents or trainees in ideal clinical practice settings would get mentored guidance on a recurring basis, thus increasing the reliability of their bedside sonographic skills with ongoing experience. Our results may be relevant in determining minimal US education and experience required for privileging for independent performance and interpretation. Ultrasound in our study was more sensitive in detecting lung abnormalities in patients on mechanical ventilator (MV). Patients on MV have presumably more discrete lung abnormalities (like consolidation or diffuse pulmonary edema), which can be identified more reliably on ultrasound and CXR, thus increasing sensitivity and specificity.

Agreement between Ultrasound (USG) operator and reviewer was modest in our study. However, the kappa was very good when only expert-expert pair is analyzed. Identification of C-pattern (and/or B-pattern only) had 100% agreement between the operator and reader. This would correlate with published reports of high agreement in detecting consolidation.[5] We, however, went further and attempted to analyze if the reader and operator also agreed upon the exact lung region for the abnormalities. The agreement remained good for C pattern but only fair for the B-pattern. B-lines themselves might be easy to identify, characterizing a B-pattern requires interpretation of these lines for significance which may be more challenging and subjective. While the overall agreement was modest, between clinical diagnosis and investigations (CXR and US), it was remarkably low for CXR interpretation and clinical diagnosis, similarly "reader" performed worse than the "operator." As both reader and CXR interpreter were blinded to the clinical picture and were not at the bedside, this data supports the conventional teaching that thoracic US and CXR has utility only in conjunction with clinical exam and not in isolation.

US examinations in children have both advantages and disadvantages. Due to the smaller size and less chest wall mass, children are more suited for thoracic US than adults.[19] Due to the small size of lungs, any pathology is more likely to abut the pleura thus increasing the chances of identification by US.[4] However, imaging in non-sedated infants is challenging, and poor image quality can lead to lower accuracy in detecting abnormalities. We have found an age group of one to five to be most ideal for the US as infants are challenging to image while adolescents chest start more closely approximate adults body wall structure.

Strengths of the study include the first study including heterogeneous PICU patients done by PICU clinicians which mimics real-world application and provider's good external validity for application in other PICUs across the country. The main limitation of the study is the use of CXR as the gold standard, due to obvious ethical reasons, obtaining a CT scan was not possible. The agreement between operator and reader and with CXR in our study is less than what has been reported in prior studies; this may be due to the blinding of the reader to the clinical presentation, which may not be an exact circumstance in the real-world application, where US is done and interpreted in real time. A large proportion of our patients were admitted for bronchiolitis, and prior studies have also shown a weak correlation of interpretation in this population.[22] CXR interpretation by pulmonologist rather than a radiologist, while clinically relevant, can be a limitation while comparing our findings to studies with radiologist reporting of CXR.

Thoracic US provide actionable quantitative data and have been utilized to monitor lung recruitment and other dynamic changes.[26,27] It has been argued that US should be considered as a gold standard in the detection of pneumonia,[4] and as a substitute for CXR when evaluating children suspected of having pneumonia.[13] While we strongly believe in the utility of thoracic US, based on our data we are unable to support this assertion in PICU and recommend further studies to better delineate the protocol for children admitted to ICU.

ACKNOWLEDGMENT

None.

CONFLICT OF INTEREST

Authors declare no conflict of Interest.

FINANCIAL DISCLOSURE

Authors have no financial relationships relevant to this article to disclose. Funding source is none.

AUTHOR CONTRIBUTIONS

Dr. Tripathi conceptualized and designed the study, designed the data collection instruments, coordinated and supervised data collection and analysis, drafted the initial manuscript, and approved the final manuscript as submitted. Dr. Ganatra, Dr. Martinez, and Dr. Mannaa carried out the initial analyses, reviewed and revised the manuscript, and approved the final manuscript as submitted. Dr. Peters supervised design and conduct of the study. He reviewed and revised the manuscript, and approved the final manuscript as submitted.

AUTHOR DECLARATION

Manuscript has not been published previously, is not under consideration elsewhere and will not be submitted elsewhere while under consideration by Clinical Ultrasound, that all authors are responsible for reported research, and that all authors have participated in the concept and design, analysis and interpretation of data, drafting or revising of the manuscript as submitted.

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How to cite this article: Tripathi S, Ganatra H, Martinez E, Mannaa M, Peters J. Accuracy and reliability of bedside thoracic ultrasound in detecting pulmonary pathology in a heterogeneous pediatric intensive care unit population. *J Clin Ultrasound*. 2019;47:63–70. https://doi.org/10.1002/jcu.22657